

# Exhibit 11

## TECHNICAL NOTE



# Uncooled detectors for thermal imaging cameras

## Making the right detector choice

*In the last few years thermal imaging has found its way into many more commercial applications. Most of these applications require a low cost product with an uncooled detector. These sensors image in the LWIR, or longwave infrared band (7 - 14  $\mu\text{m}$ ). Different types of uncooled detectors are available on the market. Since the infrared detector is the heart of any thermal imaging camera, it is of the utmost importance that it is of the best possible quality.*

*Uncooled detectors are made of different and often quite exotic materials that each have their own benefits. Microbolometer-based detectors are either made out of Vanadium Oxide (VOx) or Amorphous Silicon ( $\alpha\text{-Si}$ ) while there*

*also exists a ferroelectric technology based on Barium Strontium Titanate (BST).*

*Users of thermal imaging cameras should get the best and most modern technology if they decide to purchase a system for whatever application. The ability to see crystal clear pictures through darkness, fog, haze and smoke all depends on the quality of the detector. Understanding the different technologies for uncooled detectors that are currently on the market can help in making the right choice.*

### **Thermal imaging: initially developed for the military**

Thermal imaging is a technology that originated in military applications. Thermal imaging cameras produce a clear image on the darkest of nights. They need no light whatsoever to operate, and allow seeing without being seen yourself. Thermal imaging cameras can also see to some extent through light fog, rain and snow. They also have the ability to see through smoke which makes it even more interesting for military users since they can see across a smoke-covered battleground.

The first thermal imaging cameras for the military were developed in the 1950's. Although they had the ability to create a clear image on the darkest of nights, they were bulky systems that were hard to field.

The technology used at that point in time required that the camera was filled with liquid nitrogen. The systems were extremely expensive and the military had a lock on the technology because it was classified.

The military has always been convinced that thermal imaging is an extremely useful technology. In the beginning of the 1970's the US Military wanted to bring the technology to every soldier. In order to do so, thermal imaging cameras needed to become a lot more compact, portable and definitely a lot less expensive. It became very clear that in order to reach this objective, cooled detectors needed to be replaced by uncooled detectors. Research into this field was necessary.



*The first thermal imaging cameras were bulky systems that needed to be filled with liquid nitrogen*

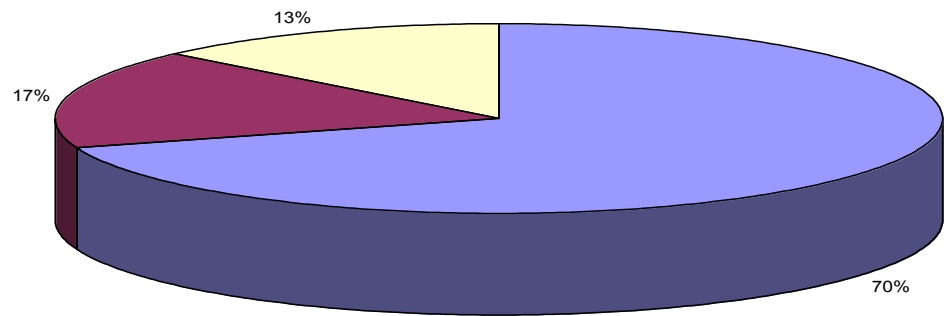


### Vanadium Oxide, Barium Strontium Titanate, Amorphous Silicon: what is the most popular today?

Looking at these three technologies, it is undoubtedly Vanadium Oxide that is winning the battle between the technologies. There are now far more companies that are producing Vanadium Oxide detectors. This obviously reflects in the number of detectors that are being produced worldwide. As with all products, when volumes go up, prices go down, thanks to economies of scale. Today Vanadium Oxide detectors are being produced at a much lower cost than either of the two other technologies.

It is significant to see that so many important manufacturers and demanding users are choosing Vanadium Oxide.

Estimated market shares for VOx - a-Si and BST detectors



*VOx is clearly the most used technology for uncooled detectors*

Vanadium Oxide 70%    Amorphous Silicon 17%    Barium Strontium Titanate 13%

### Noise Equivalent Temperature Difference (NETD)

The noise rating of an infrared detector specifies the amount of radiation required to produce an output signal equal to the detectors own noise. Practically, it specifies the minimum detectable temperature difference.

Being able to detect the minute temperature differences is important in most thermal imaging applications. A thermal imaging camera which is capable of detecting extremely small temperature differences will "see" more in all circumstances, and certainly in environments where thermal contrast between the background and an object is minimal. As such, a better NETD value will provide for better range performance, i.e. a person can be seen at a longer distance.

When comparing NETD values of different thermal imaging cameras, it is important to realize that manufacturers measure this using different parameters. One important parameter that needs to be taken into account when specifying the NETD value of a thermal imaging camera is the f-number of the lens that was used for doing the measurement.

### Comparing NETD values

If we want to compare the NETD values of different detectors, it needs to be done by using a lens with the same f-number.

### VOx versus BST

NETD values of BST detectors are often measured with a lens with an f-number = 1. Values for Vanadium Oxide detectors are often measured with a lens with an f-number = 1.6

Comparing the NETD might give the following values:

BST: 0.1 Kelvin at 25°C with f = 1

VOx: 0.1 Kelvin at 25°C with f = 1.6

At first glance, both systems have the same noise performance. But if the values are recalculated to the same f-number, then a totally different picture emerges:

BST: 0.1 Kelvin at 25°C with f = 1

VOx: 0.039 Kelvin at 25°C with f = 1

**Clearly, if a lens with the same f/number is used, VOx produces a result which is nearly three times better than BST. The same goes when VOx is compared to a-Si.**

The conclusion of this comparison is that VOx detectors are the most sensitive. They make the smallest of temperature differences apparent. This is important in any thermal imaging application.

### VOx versus a-Si

VOx detectors have an impedance of around 100Kohm for a typical resistor. This is an important advantage over a-Si detectors that typically have an impedance of 30Mohm.

A resistor of 100Kohm will have a higher current running through it at the same voltage and therefore the Johnson noise (or thermal noise) will be lower.

The Johnson noise voltage of a resistor is modeled as follows:

$$E = (4 k T R \Delta f)^{1/2} \text{ (V RMS)}$$

where

E = the Root-Mean-Square or RMS voltage level

k = Boltzmann's constant ( $1.38 \times 10^{-23}$ )

T = temperature in Kelvin  
(Room temp = 27 °C = 300 K)

R = resistance

$\Delta f$  = Circuit bandwidth in Hz  
(Assumes a perfect brickwall filter)

### What is the f/number of a lens

In optics, the f/number (sometimes called focal ratio, f/ratio, or relative aperture) of an optical system expresses the diameter of the entrance pupil, (this is a virtual aperture that defines the area at the entrance of the system that can accept light), in terms of the effective focal length of the lens. In simpler terms, the f/number is the focal length divided by the aperture diameter.

Generally speaking, a lens with a higher f/number is a lens with a smaller diameter.

It is easy to understand that a lens with a big aperture diameter allows for more light, or infrared radiation, to go through it. Consequently, more infrared radiation will reach the detector, which means that the detector will react more to this incoming radiation. Under the same circumstances, with the same detector, a thermal camera will have much better NETD values when the measurement is done with a lens with a large diameter or low f/number.



*A lens with a higher f/number has a smaller diameter*

The Johnson noise voltage is predictable and depends on three conditions: resistor value, circuit bandwidth and temperature. The higher the resistor value, the higher the Johnson noise. This will be seen as "random speckle noise" in the image quality of a thermal camera. Johnson noise is one of the main contributors to noise in the image of an uncooled detector.

## Uncooled detectors: a brief history

Two basic uncooled detector types have emerged today. Ferroelectric detectors and microbolometers.

### Ferroelectric detector

Ferroelectric detector technology takes advantage of a ferroelectric phase transition in certain dielectric materials. At and near this phase transition, the electric polarization of the dielectric is a strong function of temperature. Small fluctuations of temperature in the material cause large changes in electrical polarization. If the sensor is maintained at a temperature near the ferroelectric phase transition and if the optical signal is modulated (with a synchronous chopper), then an infrared image can be obtained.

### Microbolometer

A microbolometer is a specific type of resistor used as a detector in a thermal camera. It is a tiny vanadium oxide (VOx) or amorphous silicon (a-Si) resistor with a large temperature coefficient on a silicon element with large surface area, low heat capacity and good thermal isolation. Infrared radiation from a specific range of wavelengths strikes the vanadium oxide or amorphous silicon and changes its electrical resistance. Changes in scene temperature cause changes in the bolometer temperature which are converted to electrical signals and processed into an image.

In the 1970's, two companies started research to develop uncooled infrared detectors. The US Government awarded HIDAD (High-Density Array Development) contracts to both companies, for the development of thermal imaging technology for practical military applications.

In 1978, one of the companies patented ferroelectric infrared detectors, using Barium Strontium Titanate (BST). The technology was demonstrated to the military for the first time in 1979.

At the same time however, another technology was developed: Vanadium Oxide (VOx) microbolometer technology.

### VOx versus BST

The US military provided funding for both companies to develop their thermal imaging technology into equipment systems including rifle sights and driver vision enhancement systems. They strongly believed in thermal imaging systems with uncooled detectors and wanted to further develop both BST and VOx detector technology. This way the US military would have a choice of technology.

About 10 years ago this changed. At that point in time, convinced of the advantages VOx has over BST, the US Military decided not to provide any more funding for research into BST technology. From that point in time, only further research in VOx was supported.

As in all areas, research into new uncooled detectors is very expensive. The loss of government funding for BST meant that research in this technology slowed down drastically. While VOx technology developed, and is still continuing to do so, the research into BST stagnated. Furthermore, the company that developed



*Today, the US Government is convinced that VOx has numerous advantages over BST*

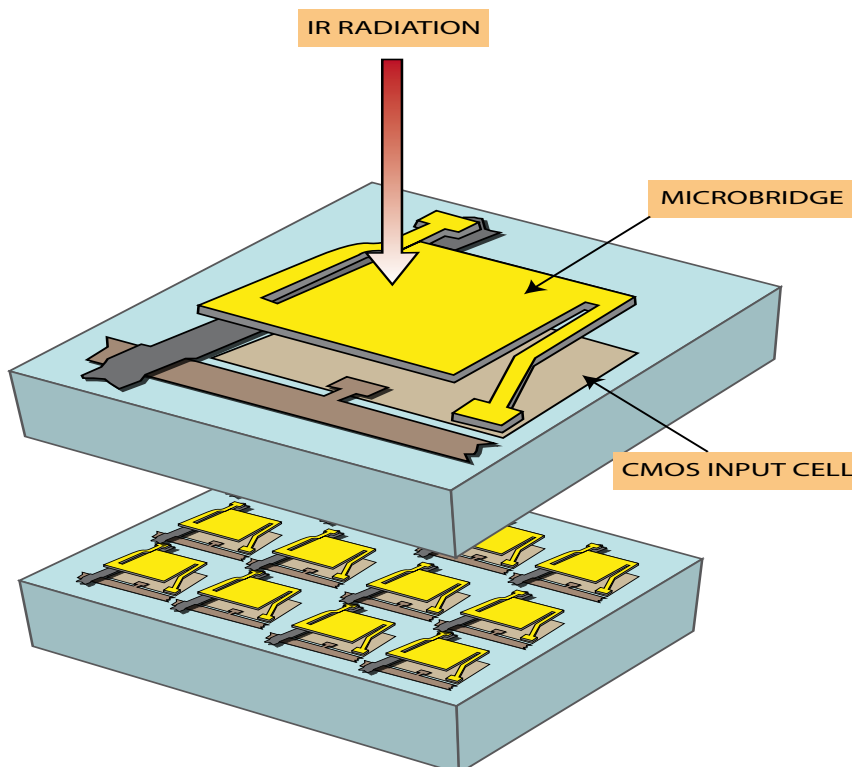
BST technology kept it for itself while the VOx technology was licensed to different manufacturers. Today, only one company is still producing BST detectors. In March 2008, this company announced that it is phasing out the production of uncooled BST ferroelectric FPAs and cameras. The company expects to stop producing BST detectors in mid-2009.\* VOx is being produced by numerous manufacturers that made the same choice as the US military.

### A third technology: Amorphous Silicon

In the mid 90's a third technology was developed. Instead of using a thin layer of Vanadium Oxide to coat the microbolometer, a thin layer of Amorphous Silicon (a-Si) was used. The big advantage of using Amorphous Silicon at that point in time was that uncooled detectors could be fabricated in a silicon foundry. Furthermore, the Vanadium Oxide technology was still controlled by the US military which meant that an export license was required for thermal imaging cameras with a VOx microbolometer detector that were sold outside the US.

Today both reasons for using Amorphous Silicon instead of Vanadium Oxide have disappeared. Vanadium Oxide detectors can also be produced in a silicon foundry. The best example is FLIR Systems detectors. Together with AMI Semiconductor (AMIS), a leader in the design and manufacture of silicon solutions, FLIR Systems is investing in a new production facility for Vanadium Oxide detectors. It will be part of a normal silicon foundry.

The exportability issue is also slowly starting to become obsolete. The US Government knows that applications for thermal imaging cameras are rapidly emerging and they do not want to deprive US companies of the huge growth possibilities connected to this technology. Therefore Vanadium Oxide detectors with an image frequency of 8.3 Hz PAL / 7.3 Hz NTSC are already freely exportable worldwide (with some restrictions such as for embargoed countries). Systems with a higher image frequency of 25 Hz PAL/30 Hz NTSC can be exported with a simple Department of Commerce (DOC) export license, as opposed to a more difficult to obtain State Department license.



*Schematic overview of a microbolometer detector. A bolometer is a small plate that floats above the surface of a Read Out Integrated Circuit (ROIC). The temperature of the plate changes when a photon falls on it.*





*The lenses of a thermal imaging camera are made of Germanium.*



### Lenses of thermal imaging cameras: size does matter

If a bigger lens allows one to build more sensitive thermal imaging cameras, the question can be raised: why are manufacturers that are producing thermal imaging cameras with VOx detectors not using lenses that are equally big as the ones used on thermal imaging cameras with BST or  $\alpha$ -Si detectors?

Lenses of thermal imaging cameras are different from lenses of normal cameras. Glass does not transmit infrared radiation well and so the lenses

of a thermal imaging camera are made of germanium. This material is a good transmitter of infrared radiation. However, it is a very expensive material.

Using a lens with larger diameter increases the price of the lens, and consequently the price of the thermal imaging camera, drastically. That is why thermal imaging camera manufacturers try to use lenses with a small diameter, or high f-number.

If we combine this with the fact that VOx detectors can be produced less expensively than BST and  $\alpha$ -Si detectors, thermal imaging systems with big lenses, such as systems with a BST or  $\alpha$ -Si detector, will be more expensive than cameras with a VOx detector.

### Camera size

But there is more. Mounting a big lens on a camera has other disadvantages. The center of gravity will move towards the front of the camera. This makes the thermal imaging camera heavy and more difficult to handle. Furthermore, the entire system will be bigger. This is an important factor if the camera needs to be integrated in confined spaces such as cars, UAV's or other small (handheld) devices, but also when they need to be mounted on poles for security and surveillance applications, on ships, ...



*Left image is produced by a VOx detector. The right by a BST detector.  
Notice the difference in image quality and focus depth.*

### Focus depth

Finally the depth of focus is very shallow for big, low f-number lenses. Practically speaking, this means that the foreground will be in focus but the background will be out of focus. When looking at a human face, the nose might be in focus but the ears will be out of focus. If we project this to another situation, the man walking very close to the thermal imaging camera will appear very sharp, but the background will not. Seeing what is happening in the background is equally important.

When investing in a thermal imaging system, the user should be sure that the camera is easy to handle and to install and as small as possible. Furthermore it should detect the smallest of temperature difference so that more details can be seen on the thermal image. A thermal imaging camera with a Vanadium Oxide detector is therefore the obvious choice.



*The size of a thermal imaging camera is an important factor if the camera needs to be integrated in confined spaces such as cars.*

### Pixel size

Just like every digital image, a thermal image is built up by a number of individual pixels. The minimum size of the pixels produced by a BST detector is 50 microns. Both VOx and  $\alpha$ -Si detectors can produce pixels as small as 15 micron. This allows for smaller lenses and therefore cheaper and more compact camera systems.

Since the pixels produced by a VOx or  $\alpha$ -Si detector can be a lot smaller, these technologies evolved into detectors that can produce thermal images of 640 x 480 pixels in a reasonably small array. This is a four times better image than the 320 x 240 pixels images to which BST detectors are restricted. It is another clear example about how VOx and  $\alpha$ -Si detectors have evolved while BST technology is still at the same point where it was more than 10 years ago.

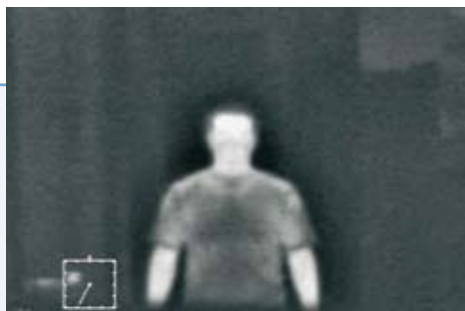


*A ferroelectric detector has a continuous rotating chopper which is susceptible to breakdowns.*

### Ferroelectric versus microbolometer focal plane arrays

As described in the beginning of this article there is a difference between ferroelectric detector technology, which uses BST, and microbolometer detector technology using VOx or  $\alpha$ -Si.

Because ferroelectric sensors are AC coupled, there is an internal mechanical chopper that



*BST detectors are susceptible to the halo affect. A dark ring surrounds brighter hotter objects.*

### Who is using which type of detector?

Probably the most demanding customer in the world is the US Military. They insist on having the best possible equipment since the lives of thousands of people can depend on it. The US Military has firmly chosen Vanadium Oxide technology. It is being used in virtually all their thermal imaging equipment which contains an uncooled detector.

At the same time, significant industrial companies have expressed their choice for Vanadium Oxide. Just one example is BMW, one of the most prestigious car brands in the world. A recent innovation to help drivers see better at night is the "BMW Night Vision" system. BMW opted for thermal imaging cameras with Vanadium Oxide detectors for their driver vision enhancement system



*BMW opted for thermal imaging cameras with Vanadium Oxide detectors for their driver vision enhancement system*

which can be ordered as an option on selected BMW 7-, 6- and 5-series models.

recalibrates the image. This so-called Auto Image Calibration (AIC), is actually a continuously rotating "chopper". This is needed because the only way that a ferroelectric BST detector can create an image based on temperature differences is by continuously switching the signal that is falling on the detector on and off and then sampling the difference between the successive frames.

The continuously rotating chopper blocks the detector 50% of the time. This means that half the time the detector is not receiving any infrared radiation from the scene. This does not benefit the sensitivity of the camera.

A continuously rotating mechanical device is also very susceptible to breakdown, and is very sensitive to shock and vibration. The Mean Time Between Failure (MTBF) for a ferroelectric BST camera is therefore a lot shorter than for a thermal imaging camera with a microbolometer detector, especially in harsh environments.

Microbolometers also have an internal mechanical calibration device. This NUC "paddle" will periodically flag in front of the detector. It freezes the image for a fraction of a second and recalibrates it. However, it is only blocking the detector from the scene very briefly and is less susceptible to breakdown compared to a chopper.

### Image retention and Halo effect

Image retention is a phenomenon where there is a temporary "burn in" when looking at a certain object. An example we all know is when you look directly at the sun. When you look away an image of the sun will persist in your eyesight for a couple of seconds.  $\alpha$ -Si detectors are more prone to this phenomenon than VOx detectors.

### Thermoelectric Cooler

In ferroelectric BST detectors, thermoelectric coolers (TECs) are utilized to temperature stabilize the IR detector insuring that what the camera measures is resulting only from external photonic sources. VOx detectors (and some  $\alpha$ -Si detectors) do not require this Thermoelectric Cooler.

The advantages of not having to use a TEC are many. Apart from enabling the camera to operate over a wide temperature range while maintaining excellent dynamic range and image quality, two other significant benefits are realized from TEC-less operation: reduced power consumption which is important in battery operated applications, and "instant-on" capability. The time to image is less than 2 seconds – ideal for on-demand applications like firefighting.



*Not having a Thermoelectric Cooler is a big advantage in firefighting applications, since cameras are turned on and off to conserve battery power and any delays in producing an image can be potentially dangerous.*

A halo is a ring of light that surrounds an object. The same effect can appear on a thermal image, and BST detectors are very susceptible to this. Most of the time this happens with hotter objects. They are surrounded with a dark ring. Needless to say, this is not benefiting the image quality.

## Conclusion

When deciding to invest in a thermal imaging camera with an uncooled detector, make sure you buy a system with a modern detector. Although manufacturers of different technologies will come up with their own arguments to support that their technology is the best, one might consider the following points:

- **Detector sensitivity:**

When comparing different types of detectors under the same circumstance (using lenses with the same f/number) Vanadium Oxide will undoubtedly come out as the most sensitive material allowing the user to see better than with any other uncooled detector material.

- **Cost/ volume**

Vanadium Oxide is produced in far higher quantities than any other uncooled detector. Thanks to these high volumes, prices have come down considerably. Often a thermal imaging camera with a Vanadium Oxide detector will be less expensive. If not, it will definitely give you the best value for your money.

- **Reliability / ruggedness**

Vanadium Oxide cameras are more reliable than BST detector-based cameras. They do not need a "chopper" to produce an image. This means that they have less moving parts which reduces the possibility of a breakdown drastically.

- **Availability**

Since so many manufacturers are producing Vanadium Oxide detectors, there is a lot more supply. They are available immediately which means that the delivery time of a camera with a VOx detector can be much shorter.

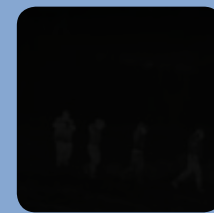
- **Who is buying which technology and what are the applications of the different technologies?**

Although cameras with BST detectors are still being used and sold for various applications, the most demanding users have chosen for VOx technology. Examples are not only the US military but also industrial companies like BMW which have chosen thermal imaging cameras with Vanadium Oxide microbolometer detectors for their driver vision enhancement system.

Although all these considerations are very important and can help to make a decision about which technology to use, you need to evaluate the entire thermal imaging camera and not only its detector. However, the type of detector that is inside the camera will have a huge impact on the performance of the entire camera system.

**A thermal imaging camera with a Vanadium Oxide microbolometer detector will likely be more compact, more sensitive and less expensive. The Mean Time Between Failure will be a lot higher than for any other detector.**

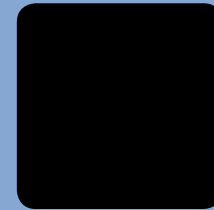
Furthermore, contrary to other detector technologies, there is still a lot of research being done into VOx technology. This means that differences between VOx and the other technologies will only become even bigger in the future.



Visual image



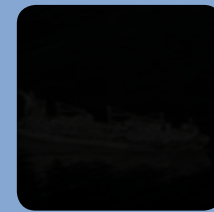
Thermal image



Visual image



Thermal image



Visual image



Thermal image



Visual image



Thermal image

Worldwide, numerous users of thermal imaging cameras have discovered that a thermal imaging camera with a Vanadium Oxide detector gives the best results for their application

\* Source: Infrared Imaging News, Volume 14, Issue: 4, April 2008



Photon 320

Photon 640

The Photon 640 is equipped with a Vanadium Oxide Microbolometer detector with a 25  $\mu\text{m}$  pitch. It produces crisp thermal images of 640x480 pixels in which the smallest of details can be seen. Users that do not need such a high image quality can choose for the Photon 320. This thermal imaging camera is equipped with a Vanadium Oxide Microbolometer detector with a 38  $\mu\text{m}$  pitch producing thermal images of 320x240 pixels.

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